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Study of Maintenance Deficiencies, Operating Horsepower, Fuel Efficiency, and Pump Efficiency of Internal Combustion Engine Powered Pumping Plants

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STUDY OF MAINTENANCE DEFICIENCIES, OPERATING HORSEPOWER, FUEL EFFICIENCY, AND PUMP EFFICIENCY OF INTERNAL COMBUSTION ENGINE POWERED PUMPING PLANTS

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser Date

Head, Agricultural
Engineering Department Date

266.23

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STUDY OF MAINTENANCE DEFICIENCIES, OPERATING HORSEPOWER, FUEL EFFICIENCY AND PUMP EFFICIENCY OF INTERNAL COMBUSTION ENGINE POWERED IRRIGATION PUMPING PLANTS

INTRODUCTION

The transition of sugar beet production from Western South Dakota to the southeastern area of the state, in 1964 and 1965, brought many changes in cropping practices. These changes occurred in the preparation of the seedbed, the seeding process, cultivation practices and methods of harvesting. The farmers, who switched to beet production, in this area were confronted with cropping practices that were completely foreign to them. They were offered assistance by Sugar Beet Company fieldmen, Cooperative Extension personnel and South Dakota State University research personnel. With an experienced background in sugar beet production, the company fieldmen were able to direct the farmers in their new cropping practices and general machine operation.

However, this new area of production necessitated the advent of irrigation on the majority of the producers' farms. While irrigation was not new in South Dakota and was not new in the enterprise of beet production, it was new to the farmers in this area. The majority of these farmers had followed the ways of their predecessors and were strictly dryland producers. In view of this lack of knowledge concerning irrigation practices, an educational program was conducted for the operators in this area. The basic principles of irrigation were discussed with the farmers and assistance was provided for them to aid in the establishment of their respective irrigation units. An area irrigation specialist was employed to work directly with these farmers to assist them in establishing and maintaining their irrigation systems. After working with these irrigators for a time, it was apparent there was a need for more specific information regarding the actual operating efficiencies of the irrigation units. This information would enable the field specialist to accurately point out the locations of inefficiencies in the respective irrigation systems.

With this need in mind two studies were implemented in conjunction with each other. One study was to determine the specific yield and recovery rate of specified irrigation wells. The other study, with which this paper has the main concern, was to determine the operating performance and maintenance of the internal combustion engines being used with the specified wells. The results of these two studies should assist in determining the specific area, in the irrigation pumping plant, that needs improvement so that adjustments can be made to improve the efficiency. This improvement of efficiency could result in a larger net financial return to the respective farmer by lowering his operating expenses.

REVIEW OF LITERATURE

Irrigation has been practiced in the United States since the year 600 A.D. when the Hohokam Indians along the Salt River Valley in the Southwest United States dug canals to convey irrigation water.(21) Modern irrigation was started in 1847 by the Mormon pioneers in Salt Lake Valley in Utah. Until the late 1940's and early 1950's most of the land was irrigated with surface water. The great increase in the use of groundwater occurred from the late 1940's to the present.(22) The main reason for this great increase was due largely to improvements in well drilling techniques, more efficient pump and power units, and the general availability of power on the farm. As the source of power became more dependable, the irrigation farmer was able to increase the dividends from his investment in irrigation equipment.

One of the earliest discussions on power units for irrigation was in 1954 by T. V. Wilson, Associate Professor of Agricultural Engineering at North Carolina State University.(25) His paper was a discussion of important factors to be considered when selecting a power unit and an economic comparison of internal combustion engines and electric motors as a power source.

His discussion covered the physical and environmental factors that required attention in power unit selection. He believed that the number and accessibility of pump setups that were contemplated was a factor of importance. Wilson contended that if a number of pumping locations were to be utilized, then the cost of running power lines to each site would be prohibitive and gasoline or diesel engines would have to be used. His only restriction for location of internal combustion engines would be from the standpoint of getting equipment in place and convenience of hauling fuel to the engine.

His second factor of consideration was the availability of fuel and electricity in the pump area. Availability is usually no problem for fuels. Also most farmers have single phase electric service available. Therefore, in these specific cases electric motor installations would have to be limited to 7½ horsepower or less. As a result, the irrigation capacity was limited to 25 acres with the single phase motor. This led to his third factor which was the size of the unit needed determined the type of power to be used. His choices were: up to 7½ horsepower, gasoline or electricity; 7½ to 40 horsepower, gasoline (or electricity if three-phase service was available); and 40 horsepower and above, gasoline or diesel.

His fourth factor to consider was the initial cost of the power unit. He suggests that an old engine or large tractor that might be available during irrigation periods could be used to keep the initial investment at a lower figure.

Wilson also discusses the operating characteristics of internal combustion engines and electric motors. He suggests selecting an engine size that will give maximum pump efficiency at 70% of the engine's maximum horsepower. He believed that the source of most pumping plant troubles was on-the-farm matching of old engines or farm tractors and pumps. Another problem was competitive salesmen selling commercially available power units too small for the existing or designed pump in the interest of quoting lower prices in order to make a sale.

An economic comparison was made between the operating cost of electric and gasoline power units. In North Carolina, in 1954, it cost less on the average to use electric motors rather than gasoline powered engines. The relative costs of gasoline and diesel fuel indicated an equal cost at 40 horsepower when operated an average of 360 hours per year. If the annual operating time was less, the horsepower figure would be above 40, and if annual operating time was more the horsepower figure would be below 40.

In 1955, Mr. John Shrunk, working for the Irrigation Equipment Company, Inc., published a design handbook for sprinkler irrigation systems.(18) In this handbook he compiled the observed fuel consumption performance of irrigation pumping units. He listed the "observed average", "observed range" and "probable maximum" of fuel efficiency, for respective power sources, in terms of "Brake Horsepower Hours per Gallon" and "Water Horsepower Hours per Gallon". For the "probable maximum water horsepower" he assumed an engine efficiency of 88%, a pump efficiency of 75% and based engine performance on Nebraska Tractor Test Reports. Using this table the operator is able to predict his expected fuel consumption when he knows the rate he wants to pump, the pumping head and the pump efficiency. The table also provides a means for an established operator to compare his fuel consumption with a calculated standard.

The United States Department of Agriculture, through the Soil Conservation Service, published a National Engineering Handbook in 1959.(23) One chapter in this handbook was devoted to pumping plants. In the "Power for Pumping" section of this chapter the authors discuss the importance of properly matching the power unit to the pump. The characteristics of the respective types of power units are also discussed. The authors also discuss the proper procedures for determining the power output of an internal combustion engine. This procedure involves using the manufacturers power curves, correcting for a 15 to 20 per cent power loss from the use of accessories, 3 per cent loss for every 1000 feet above sea level and 1 per cent loss for every 10^{o} F. above 60^{o} F. They also mention the Nebraska Tractor Testing Laboratory as another reliable source of engine performance data. The method of determining power requirements needed in a pumping installation is also illustrated.

In 1959, Paul Schleusner and John Sulek, Associate Professors in Agricultural Engineering at the University of Nebraska, published a paper that established a criteria for appraising the performance of irrigation pumping plants.(17) They suggested that an appraisal of pumping plant efficiency can be accomplished by measuring the field performance of the plant and comparing it with a criterion of performance. They established their criterion by averaging the specific fuel consumption of engines, using commercially available fuels, from data obtained from Nebraska Tractor Tests and from data supplied by engine manufacturers. The efficiency of pumps and drive units was obtained from data supplied by manufacturers. The performance characteristics of the individual units making up a pumping plant were then combined in a calculated performance criteria. They used this criteria as a basis for appraising the field performance of pumping plants. The field evaluation of irrigation pumping plants, made by the authors, is apparently one of the first that has been conducted.

This same year a field evaluation of farm tractors was made in Kansas by Floyd Reece and G. H. Larson.(16) This study was conducted by inspecting fifty farm tractors. The inspection included a check of the air cleaners, spark plugs, carburetors, ignition timing, horsepower and fuel consumption. The deficiencies were noted and corrected on each tractor. A horsepower and fuel consumption test was taken before and after the maintenance corrections to determine the extent that improper maintenance or adjustment affected the tractor's performance. The tractor's performance was also compared with the rated performance data for the respective unit as given by the Nebraska Tractor Test information.

They found that under the conditions used in their study that the tractors checked were capable of developing 74.9 per cent of maximum power as determined by the Nebraska Tractor Tests, and were using 1.32 times as much fuel. After simple adjustment and maintenance to engine governor, air cleaner, spark plugs, carburetor and timing, the tractors were capable of developing 83.3 per cent of maximum power and used 1.13 times as much fuel.

Simple adjustment and maintenance of indicated items increased maximum power an average of 3.07 horsepower per tractor, or 11.1 per cent and decreased specific fuel consumption 0.105 lb/HP-Hr or 14.4 per cent.

In 1959, Mr. Guy O. Woodward compiled and edited information concerning sprinkler irrigation into book form.(26) He has devoted one section of this book to sources of power for pumping. This compilation of information was gathered from previously published authoritative sources, through correspondence, and by personal interviews with college, university, governmental and industrial scientists.

In this publication, Mr. Woodward has discussed the selection of power units and matching them to pumps. He has developed tables for determining horsepower losses for continuous speed operation, changes in elevation and changes in temperature. He has also shown curves for estimating and rating performance of power units and pumping plants. He shows a table with a calculated performance standard for new deep-well pumping plants to be used as a comparison in field evaluation.

In considering the work and investigations in the field of irrigation pumping plants, there appears to be very little that has actually been accomplished and recorded in a field evaluation of the operating power plants. General information concerning basic engine performance, in book form, has been published by Fred R. Jones (13) and also in a cooperative effort by E. L. Borger, W. M. Carleton, E. G. McKibben, and Roy Bainer.(2)

OBJECTIVES AND SCOPE

Considerable speculation has existed regarding the pumping plant operating procedures and efficiencies on our South Dakota farms where irrigation is practiced. Without such knowledge of actual operating problems it is impossible to know the areas of concentration that are in need of educational guidance. In order to resolve this speculation, this study was proposed to attempt to find suitable methods of measuring field performance of engines in the pumping plant operation. This study was also designed to gain information concerning the power output of the respective engines, which in turn would be used to determine pump efficiencies. It was the author's purpose to observe maintenance deficiencies existing on the engines that might substantiate a need for educational programs in the future. It was also the author's purpose to compare actual operating performance of the respective engines with the manufacturers rated performance standards.

Objectives of this study were:

1. Observe and record maintenance deficiencies of 25 engines used on irrigation pumps.
2. Obtain operating horsepower which could be compared with engines rated horsepower.
3. Determine respective pump efficiencies by using the engine horsepower input with the water horsepower output.

4. Obtain fuel consumption measurements which would enable a comparison to be made with manufacturers rated fuel consumption, manufacturers rated fuel efficiency, and expected performance standards.

TESTING PROCEDURE

This study of irrigation systems, and pumping plants specifically, was coordinated with Mr. Fred Schmer, Area Irrigation Extension Specialist in southeastern South Dakota. He agreed to arrange for 25 irrigating farmers in the area who would be willing to have a study made of their setup. After these cooperators were arranged for, they were each visited briefly to gain a familiarization of their setup and to obtain the specifications of their respective pumping plant. The engine specifications obtained were the make, model number, serial number, type of drive unit and the type of fuel used.

With this data, the year manufactured was determined, where possible, for the power units.(12) This data was also used in categorizing the units by type of drive used and type of fuel. Categorizing allowed scheduling of the study visits in a sequence that minimized the necessity of frequent interchange of testing equipment.

Each farm was then revisited to make the needed measurements. Due to conflicts and change of attitudes some of the original cooperators decided, at the last minute, against participation in the study. Other irrigators were contacted, as a result, in hopes of maintaining the original number of visits in the study. But due to numerous conflicts of interest and time, 22 irrigators cooperated in the final study.

At each pumping plant several items were checked. Each power unit was given a visual inspection for maintenance deficiencies in the cooling, ignition, fuel, air intake and lubrication system.

As most units were in operation it was necessary to shut them down so that the necessary measuring instruments could be connected for the testing. These were the instruments for measuring operating horsepower and fuel consumption. At the same time the instruments for a concurrent study to obtain water flow and pressure were installed. The power units were then restarted and the necessary data was obtained and recorded. Due to the operator's impatience with shutdown time and unforeseen mechanical difficulties of adapting instruments to the respective pumping plant equipment, some of the measurements on some of the equipment had to be excluded from the study.

It was attempted to obtain a measurement of operating revolutions per minute, and operating horsepower of each unit. A measure of fuel consumption was taken at operating load for each unit. Two readings taken for each fuel consumption test were averaged to determine the fuel consumption of the respective power unit. The operating engine temperature of each power unit was also observed and recorded. These measurements were noted for later comparison with manufacturers' ratings and performance standards.

At the completion of the test run, the pumping plant was again shut down and the instruments disconnected for transfer to the next site.

APPARATUS AND EQUIPMENT

Fuel consumption was measured with a plexiglass fuel cylinder and stop watch. Fuel capacity of the cylinder was calibrated prior to the testing and marks were located on the side of the cylinder. A separate cylinder was used for gasoline and diesel fuel measurements. The cylinder used for gasoline was connected to a three-way valve which allowed for turning the fuel off, drawing from the engine tank, or measuring fuel from the cylinder. The cylinder used for diesel fuel measurements had the return line connected to the cylinder so that the return fuel from the injectors was accounted for during a test. A stop watch was used to time the consumption of one-forth gallon of fuel from the cylinder. The cylinder used for the diesel engines is shown in Fig. 1. The fuel consumption of the natural gas engines was measured using the gas meter.

To obtain the revolutions per minute (RPM) of the drive units, a hand tachometer was used on the power shaft or pulley. Both belt pulley and power-take-off (PTO) RPM measurements were made with the tachometer. Tachometer graduations gave readings in increments of 10, up to 1200 RPM, and increments of 20, above 1200 RPM. A direct reading was obtained from the belt pulley measurement. With the PTO measurement a direct conversion using the ratio of the diameter of the PTO shaft to the diameter of the tachometer wheel was used to obtain power unit RPM. A check measurement was made using the RPM indicator on the PTO dynamometer, which was graduated in increments of 10 RPM.

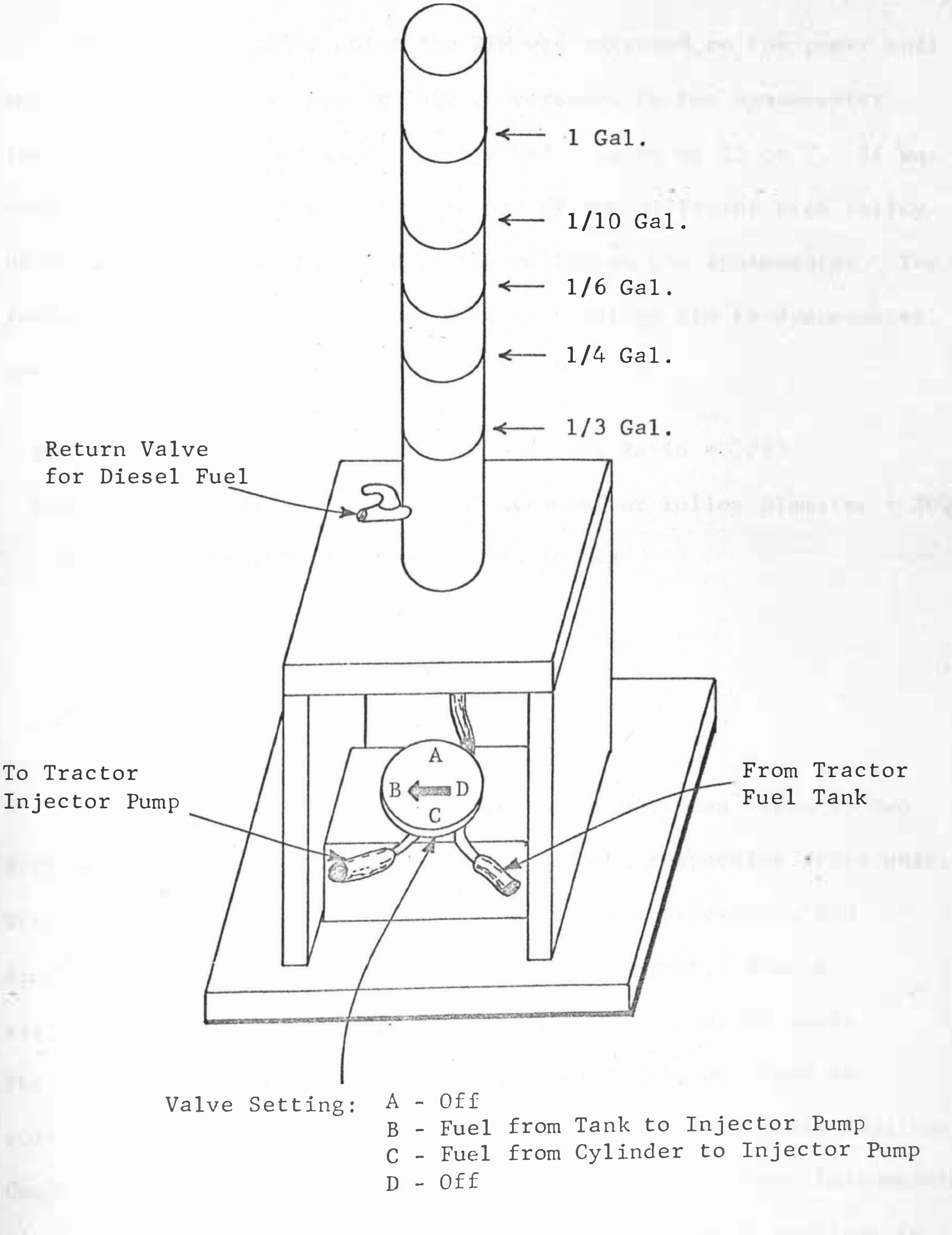


Fig. 1. DIESEL FUEL CONSUMPTION TEST CYLINDER

For the belt drive units the RPM was measured on the power unit pulley and also, with appropriate conversion, on the dynamometer tachometer. The conversion gear box had a ratio of 13 to 7. It was necessary to make a conversion because of the different size pulley on the power unit as compared to the pulley on the dynamometer. The formula for conversion of power unit belt pulley RPM to dynamometer tachometer RPM is as follows:

RPM_1 = Dynamometer RPM

RPM_2 = Power Unit RPM

D = Power Unit Pulley Diameter in inches

Gear Box Ratio = 7/13

Dynamometer Pulley Diameter = 20½"

$$RPM_1 = 7/13 \times RPM_2 \times \frac{D}{20\frac{1}{2}}$$

$$RPM_1 = .026 \times RPM_2 \times D$$

The horsepower measurement of the power unit was taken by two different methods dependent on the type of the respective drive unit. When the power source had a belt drive or was a tractor, a PTO dynamometer was used for the horsepower measurement. When a stationary engine was connected to the pump with a drive shaft, the Ellis Bridge Amplifier and Meter, Model BAM-1, was used in conjunction with an auxiliary drive shaft and a Baldwin-Lima-Hamilton Corp. SR-4 Torque Pickup, Type A. After calibration these instruments gave torque readings in inch-pounds (in-lbs) and strain readings in microinches per inch (microin/in).

To obtain the calibration factor for reading torque (in-lbs) a lever arm was fastened to the end of the measuring power shaft. The other end of the shaft was fastened securely in a vise. A load was then applied to the end of the lever arm and the appropriate calibration adjustments were made on the Ellis Amplifier. This allowed a reading of torque directly in in-lbs. Inserting this reading into the following formula gave an approximate operating horsepower which was used as a data check only.

$$HP = \frac{T \times RPM}{63{,}030}$$

T = Power shaft torque (in-lbs)

RPM = Power-take-off revolutions per minute

The recorded horsepower was obtained by using the strain as determined in microin/in. The appropriate calibration adjustments were made on the Ellis Amplifier so that the reading would be directly in microin/in of strain. This was converted to horsepower by using the following formula. The derivation of this formula is shown in the appendix.

$$HP = \frac{.0236}{1000} IN$$

I = Instrument reading strain in microin/in

N = RPM of power-take-off.

The tractor and belt drive horsepower were measured with a M & W Model-P350 Hydro-Gauge Dynamometer. The manufacturer claims this dynamometer will measure horsepower within 2 per cent accuracy. Most sources use 10 per cent accuracy as a closer figure. It consists basically of a constant volume hydraulic pump operated through a gear box which is driven by the tractor's power-take-off shaft. Pressure within the dynamometer is regulated by a large globe valve that controls the flow of oil from the hydraulic pump. Closing the valve raises pressure on the pump, this in turn loads the engine under test. Opening the valve reduces pressure on the pump which decreases the engine load. The pressure that is developed while the PTO shaft is operating is shown on a large pressure gauge dial which correlates pounds per square inch of pressure to the horsepower developed by the engine under test.

On the tractor powered units the tractor operating horsepower was measured by attaching the dynamometer directly to the tractor PTO. The tractor was run at the same throttle setting and PTO RPM as when running on the irrigation pump.

On the belt driven pumps, not powered by a tractor, the dynamometer was modified so that it could be driven by belts. The gear box, used on some models of Ford Tractors to convert the PTO drive to a belt drive, was attached to the dynamometer shaft. A V-belt pulley was attached to the pulley side of the gear box. The belts from the power unit pulley were connected to the pulley on the gear box. The power unit was run at the same throttle setting and RPM as when running on the irrigation pump.

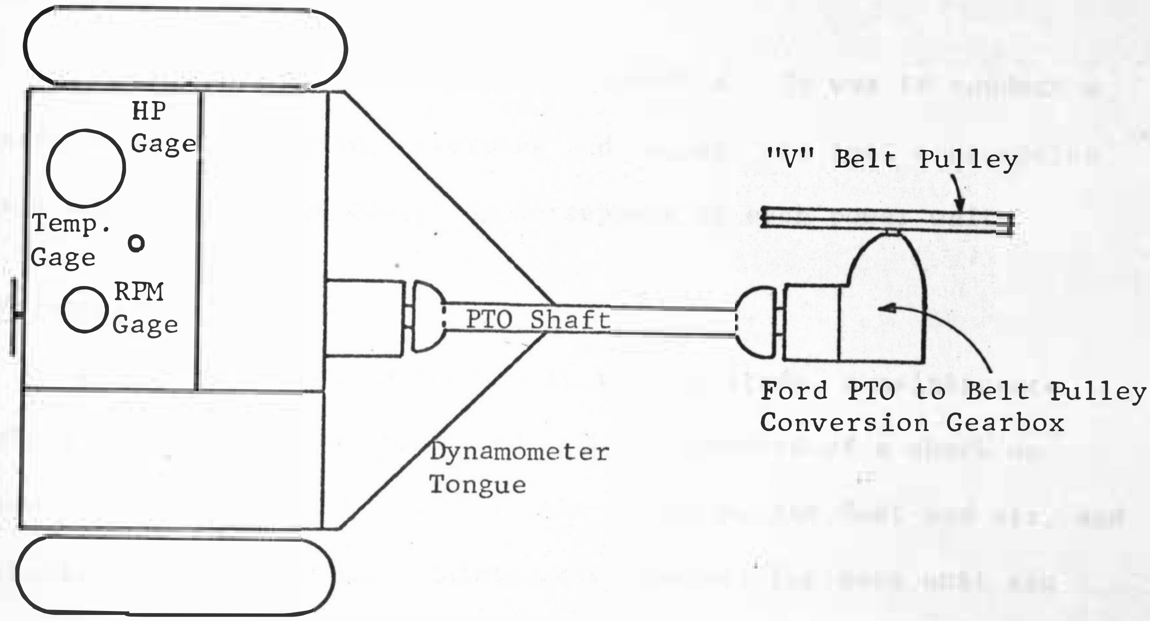
A diagram of the method of attaching the belt pulley to the dynamometer is shown in Fig. 2.

The PTO Dynamometer used in this study was calibrated with a Clayton Engine Dynamometer, Model 17-300. This dynamometer utilizes a power absorption unit using water as a loading medium. Horsepower is calculated by using the formula

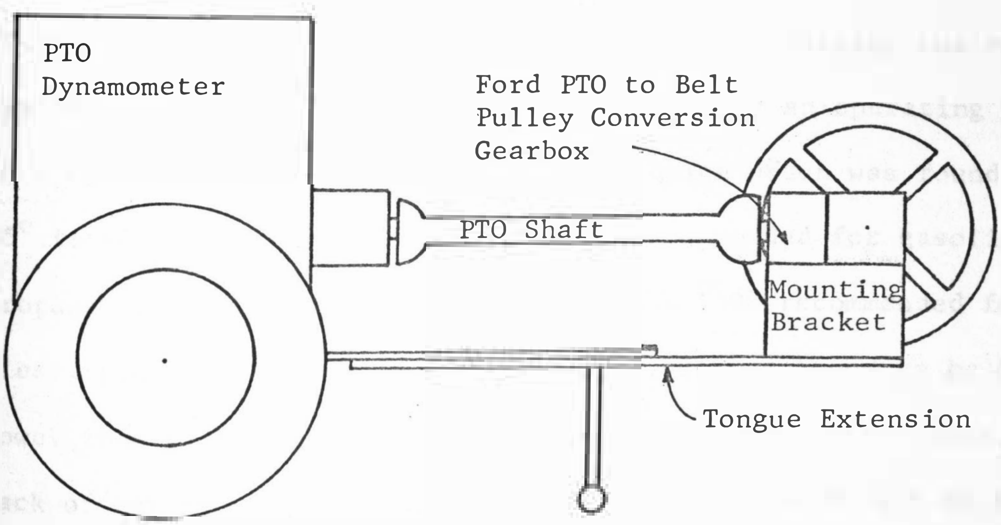
$$HP = \frac{\text{Torque (ft-lbs)} \times \text{RPM}}{5250}$$

The torque is determined by taking the length of the dynamometer lever arm, 1.75 feet for this dynamometer, times the weight that is registered on the dynamometer scale. For this dynamometer the horsepower is then calculated by this formula

$$HP = \frac{\text{Scale reading} \times 1.75 \times \text{RPM}}{5250} = \frac{\text{Scale reading} \times \text{RPM}}{3000}$$



Top View - Schematic
PTO Dynamometer Plus Belt Power
Conversion to PTO Gearbox



Side View - Schematic
PTO Dynamometer Plus Belt Power
Conversion to PTO Gearbox

Fig. 2. BELT DRIVE TEST EQUIPMENT

PRESENTATION AND ANALYSES OF DATA

The purpose of this study was threefold. It was to conduct a maintenance inspection, determine and compare the fuel consumption and economy, and the operating horsepower of each power unit.

Maintenance Check

While testing the power units, in this study, a maintenance check of each unit was conducted. This consisted of a check on four general areas; the cooling, the ignition, the fuel and air, and the lubrication systems. Maintenance comments for each unit are recorded on the Power Unit Data Sheets in Appendix C. Of the 22 power units involved in this study, only three were found without any maintenance deficiencies. See Fig. 3.

The cooling system involved the largest number of deficiencies. Fourteen of the units had some evident fault concerning the cooling system. The most common fault in this area was an operating temperature that was too low. The temperature quite often was found to run 35° to 40° lower than the 180° to 185° recommended for gasoline, propane and natural gas power units or the 190° recommended for diesel power units. In one case, test 5, it was found to be 60° lower than recommended.(19) This low temperature can account for a lack of horsepower and additional fuel consumption in all of the power units involved. Other cooling deficiencies found were that the unit in test 11 was low on water and the one in test 13 had no cap on the radiator.

Test No.	Cooling	Ignition	Fuel and Air Intake	Lubrication
1	X	0	0	0
2	0	X	0	0
3	X	0	X	0
4	X	X	X	0
5	X	X	0	0
6	X	0	0	0
7	X	0	0	0
8	X	0	0	0
9	X	0	X	0
10	0	X	X	0
11	X	X	0	0
12	0	X	0	0
13	X	X	0	0
14	X	X	0	0
15	X	0	0	0
16	0	0	0	0
17	X	0	0	0
18	0	0	0	0
19	0	X	0	0
20	0	0	0	0
21	0	0	0	X
22	X	0	0	0
TOTAL	14	9	4	1
% of Total Units Checked	70%	41%	18%	4.6%

NOTE:

X = Deficiency Observed.

0 = No Deficiency Observed.

Fig. 3. RESULTS OF MAINTENANCE DEFICIENCY CHECK.

Nine of the units in this study had an ignition deficiency. In test 2, the battery was low on power and needed a booster to start the power unit. Also, there was a short from two spark plugs to the engine housing on this unit. In test 4 the engine missed when under full load, indicating a possible ignition problem. The ignition wires were cracked quite severely on this unit. In test 5 the battery was low on charge and water. The unit had to be started with a booster battery and it was noted the ignition wires were cracked quite severely. The unit in test 10 was out of time and, after timing it properly, a horsepower increase of 30 per cent was measured. In test 11 the unit's battery was low on water and the engine back-fired when it was turned off, indicating poor timing. The units in tests 12 and 13 missed when under full load. The battery charge was low on the unit in test 14. A booster battery was unable to give the power needed to turn over this engine so a portable arc welder was hooked to the unit to get it started. The unit in test 19 had a battery that was two quarts low on water and needed a booster battery to turn the engine over.

The power units in tests 3, 4, 9, and 10 had a fuel or air deficiency. The governor in test 3 did not operate properly and a screwdriver was being used, as a wedge, to keep the governor open. The air cleaner in test 4 was very dirty. This excess dirt could easily have been contaminating the engine. The fuel line from the tank, in test 9, was almost completely plugged with a black slimy substance, which was probably contamination originating in the storage tank. The vacuum hole on the intake manifold was also completely plugged indicating an excess of deposits on the inside of the manifold. In test 10 there was no cap on the oil bath air cleaner. Therefore, unfiltered air was being drawn directly into the engine.

The only lubrication deficiency that was observed was in test 21. There was a definite oil leak from this unit but it was impossible to determine the source. Another lubrication deficiency was mentioned by the operator for test 14. This operator told how he had used a commercial additive in his engine to the extent that it plugged the oil lines and ended up as a gelatinous mass in the bottom of the crankcase. He felt this additive had caused him to have a premature major engine overhaul.

All of these maintenance deficiencies were very likely costing the operator a loss of power and increased fuel consumption. None of them were severe enough to prevent the engine from operating, but any one of them could cause difficulties in starting and a loss in the overall operating efficiency. Practically every one of these deficiencies could be corrected with very little effort or cost. It was quite enlightening to note that only the units in tests 16, 18, and 20 were free from evident maintenance deficiencies. If this is representative of all internal combustion power units involved in irrigation in South Dakota, then it could be stated that 87 per cent of all units have a maintenance deficiency of one type or another.

Results of Horsepower Measurement

The horsepower of the power units was measured by two different methods. For the gear driven units the horsepower was measured with a torquemeter and a strain gauge bridge amplifier as described earlier. The horsepower from the units in tests 1, 5, 6, 8, and 9 were measured by this method. Two readings were taken on each power unit. One reading was taken as a check. The second reading was used in the data analysis. The first reading was taken from the scale calibrated directly in inch-pounds. The second reading was taken from the instrument scale calibrated in microinches per inch. For both of these readings the speed (RPM) was measured and the horsepower was calculated using the formula(7) below:

$$HP = \frac{TN}{63,030}$$

where T equals torque, in inch-pounds, and N equals the speed (RPM). Appendix E shows the horsepower results for these tests.

The horsepower of the power units that used a belt or power-take-off drive was measured with the M & W Power-Take-Off Dynamometer which involved tests 10 through 19. The readings obtained were converted with a slide rule, furnished with the dynamometer, and the horsepower was recorded. This horsepower was then corrected by subtracting the factor 3.9, which was determined by calibration of the dynamometer.

Two series of tests were run to calibrate the PTO Dynamometer. The Clayton Dynamometer was used as the standard. A John Deere 3010 tractor was used in the first series and an International 606 tractor was used in the second series which was run on a different day. This was done to get a better estimate of any needed correction factor. Horsepower measurements were taken at nine different PTO speeds for each tractor on each dynamometer. These nine speeds were replicated five times for the first series and 12 times for the second series. The horsepower for the replication was averaged. A corrected average PTO dynamometer horsepower was calculated for the replication. This was done with the aid of the "Correction Slide Rule" as furnished by the M & W Dynamometer Company. Therefore, for each replication, the average horsepower was noted for: (1) M & W horsepower, (2) M & W corrected horsepower, and (3) Clayton horsepower. See Table 1.

A Linear Regression Analysis was then computed, using the averages of the replication. See Appendix A for the calculation. This allowed for a relationship to be established between the two variables, horsepower and PTO RPM. The averages are shown graphically in Fig. 4. The formula derived for the respective curves is as follows:

$$HP = (a) + (b) \times (\text{PTO RPM})$$

a = y intercept of regression line

b = slope of regression line

HP_1 = M & W Dynamometer horsepower

HP_2 = M & W Dynamometer corrected horsepower

HP_3 = Clayton Dynamometer horsepower

RPM = Power-take-off RPM

PTO RPM	Average Horsepower 1st Series (John Deere 3010) M&W	M&W Corrected	Clay-ton	Average Horsepower 2nd Series (International 606) M&W	M&W Corrected	Clay-ton	Average Horsepower 1st and 2nd Series M&W	M&W Corrected	Clay-ton
350	53.3	35.5	32.3	58.0	38.0	34.0	55.6	36.8	33.2
375	53.7	37.5	34.3	57.5	40.0	36.0	55.6	38.8	35.2
400	54.0	39.5	36.3	57.0	42.0	38.0	55.5	40.8	37.2
425	53.5	41.5	38.3	56.0	44.5	39.5	54.8	43.0	38.9
450	53.0	43.5	40.0	55.5	46.5	41.5	54.2	45.0	40.8
475	51.5	45.5	40.0	55.0	48.5	43.5	53.2	47.0	41.8
500	47.5	44.0	38.0	54.5	50.5	45.5	51.0	47.2	41.8
525	41.0	40.0	33.0	53.0	50.5	39.5	47.0	45.2	36.2
550	33.0	35.0	24.5	46.0	46.5	29.5	39.5	40.8	27.0

Table 1. AVERAGE HORSEPOWER FROM REPLICATION IN M&W DYNAMOMETER CALIBRATION.

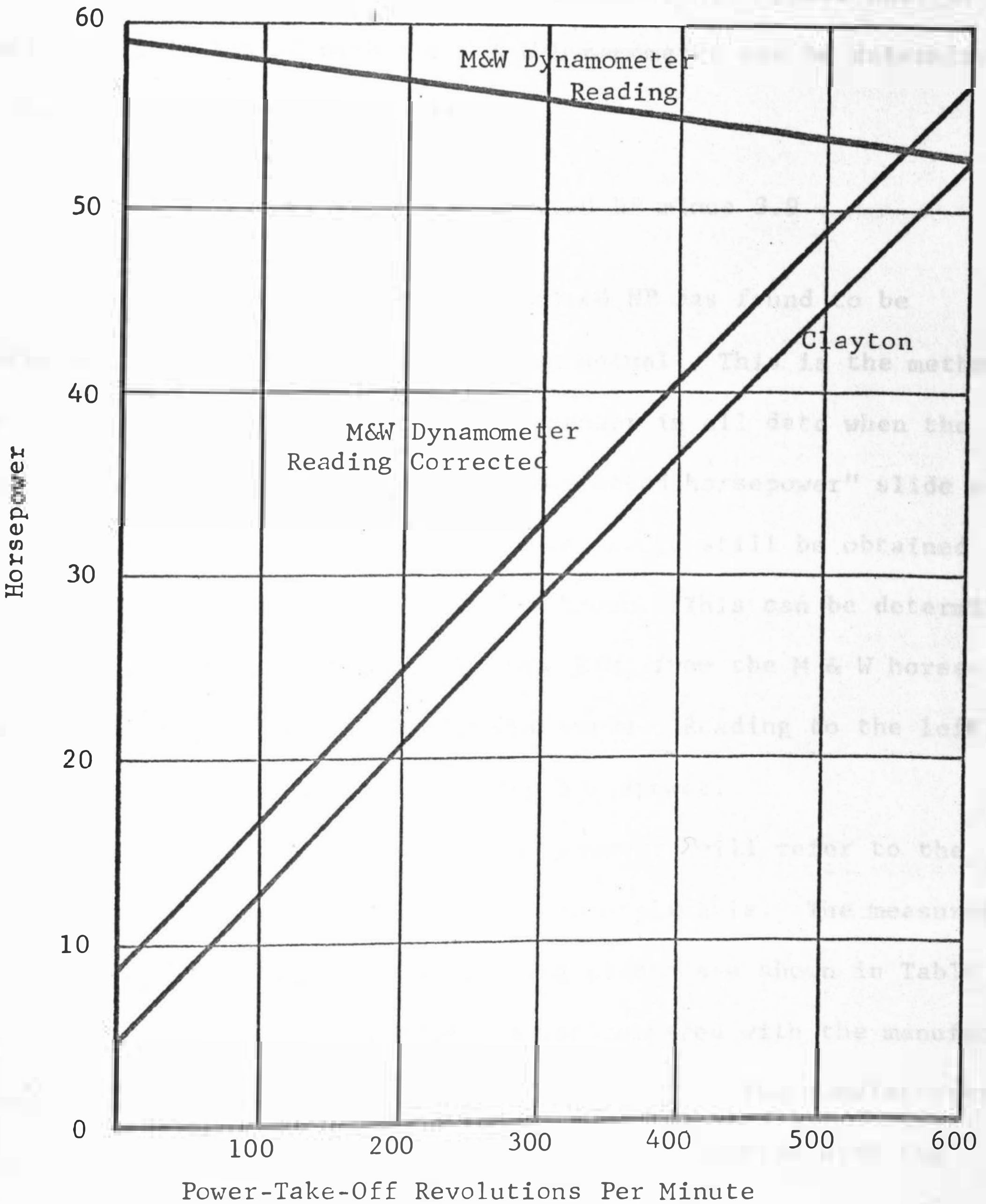


Fig. 4. CALIBRATION OF M&W POWER-TAKE-OFF DYNAMOMETER WITH CLAYTON DYNAMOMETER.

$HP_1 = 59.1 - .01\ RPM$

$HP_2 = 9 + .08\ RPM$

$HP_3 = 5.1 + .08\ RPM$

This indicates that the actual horsepower of a power unit or tractor that is tested with the M & W Dynamometer can be determined by the following formula:

Actual HP = M & W corrected HP minus 3.9

Or in other words the M & W corrected HP was found to be consistently 3.9 horsepower higher than actual. This is the method that was used to obtain operating horsepower in all data when the M & W Dynamometer was used. If the "corrected horsepower" slide rule is not available the operating horsepower could still be obtained from Fig. 3 if the M & W horsepower is known. This can be determined by reading down vertically, at the same RPM, from the M & W horsepower curve, to the Clayton horsepower curve. Reading to the left, from the "y" axis, will give operating horsepower.

Hereafter, the term "operating horsepower" will refer to the measured horsepower with corrections when applicable. The measured and operating horsepower for the pumping plants are shown in Table 2. The operating horsepower from Table 2 was compared with the manufacturers rated horsepower for the respective units. The manufacturers rated horsepower was obtained by personal communication with the respective companies.(1, 3, 5, 9, 10, 11, 14) For this comparison

Test No.	Measured Horsepower	Operating Horsepower
1	51.6	51.6
2	--	--
3	--	--
4	--	--
5	28.1	28.1
6	33.0	33.0
7	--	--
8	19.44	19.44
9	35.2	35.2
10	25.5	21.6
11	42.0	38.1
12	19.2	15.3
13	36.0	32.1
14	51.0	47.1
15	28.0	24.1
16	60.2	56.3
17	49.0	45.1
18	49.0	45.1
19	27.0	23.1
20	--	--
21	--	--
22	--	--

NOTES:

1. Where data is missing, see Power Unit Data sheets for reason.

2. For tests 10 through 19 a dynamometer correction of 3.9 horsepower was subtracted from the measured horsepower.

Table 2. CORRECTION OF MEASURED HORSEPOWER TO OPERATING HORSEPOWER.

the power units were divided into two groups. One group included stationary power units and the other group included the tractors that were used. This comparison is shown in Table 3, and graphically in Fig. 5, with the rated and operating horsepower being noted for each unit. The operating horsepower is also given in terms of per cent of rated. The per cent for the stationary units ranged from a low of 36% to a high of 178% with a mean of 101%. The tractor units ranged from 54% as the low, to a high of 118% with a mean of 91%. Rated power for a power unit or tractor is usually in the area of 85% of maximum power in order to give the unit some reserve power.(15) As a tractor becomes older its performance may drop to 50%.(24) This means that the power source in test numbers 1, 9, 10, 11, and 13 are operating in this reserve area. The units in test numbers 14 and 17 have a measured horsepower that is unreasonably high. In both cases an error could have been experienced in the testing of the engine or recording of the data. Test 17 was the first unit checked for the study and the confusion at testing time could easily have caused the error. In the case of test number 14, the operator of this unit complained about the frequent overhauls necessary to keep his unit running. A reboring of the cylinder and resultant higher compression ratio, may have occurred during these overhauls. This would give a higher horsepower. This does not exclude the possibility of an error, however. An apparent overload in test 14 is possibly a reason for the excess wear. With the exception of the extremes,

Test No.	Manufacturers Rated Horsepower	Manufacturers Corrected Rated Horsepower	Operating Horsepower	Operating Horsepower as a Per Cent of Mfgs. Corrected Rated Horsepower	Difference of Operating Horsepower from Mfgs. Corrected Rated Horsepower
			POWER UNITS		
1	66.0	50.2	51.6	103.0%	+ 1.4
2	50.2	38.2	--	--	--
3	--	--	--	--	--
4	120.0	82.2	--	--	--
5	--	--	28.0	--	--
6	74.2	50.8	33.0	65.0%	-17.8
7	--	--	--	--	--
8	79.0	54.1	19.44	36.0%	-34.7
9	45.2	34.3	35.2	103.0%	+ .9
14	36.7	26.4	47.0	178.0%	+20.6
15	36.0	26.0	24.0	92.0%	- 2.0
16	73.0	65.7	56.2	85.0%	- 9.5
17	42.0	30.4	45.0	148.0%	+14.6
20	130.0	89.2	--	--	--
21	130.0	89.2	--	--	--
22	71.0	51.3	--	--	--
			TRACTORS USED AS STATIONARY POWER UNITS		
10	28.1	20.3	21.5	106.0%	+ 1.2
11	42.8	34.3	38.0	111.0%	+ 3.7
12	41.4	33.1	15.3	46.2%	-17.8
13	33.8	27.1	32.0	118.0%	+ 4.9
18	58.1	46.5	45.0	97.0%	- 1.5
19	53.2	42.6	23.0	54.0%	-19.6

NOTES:
1. Where data is missing see Power Unit Data sheets for reason.
2. Manufacturers' corrected rated horsepower is corrected for power losses resulting from continuous load, accessories, elevation and temperature, and drive.

Table 3. COMPARISON OF MANUFACTURERS RATED HORSEPOWER WITH OPERATING HORSEPOWER.

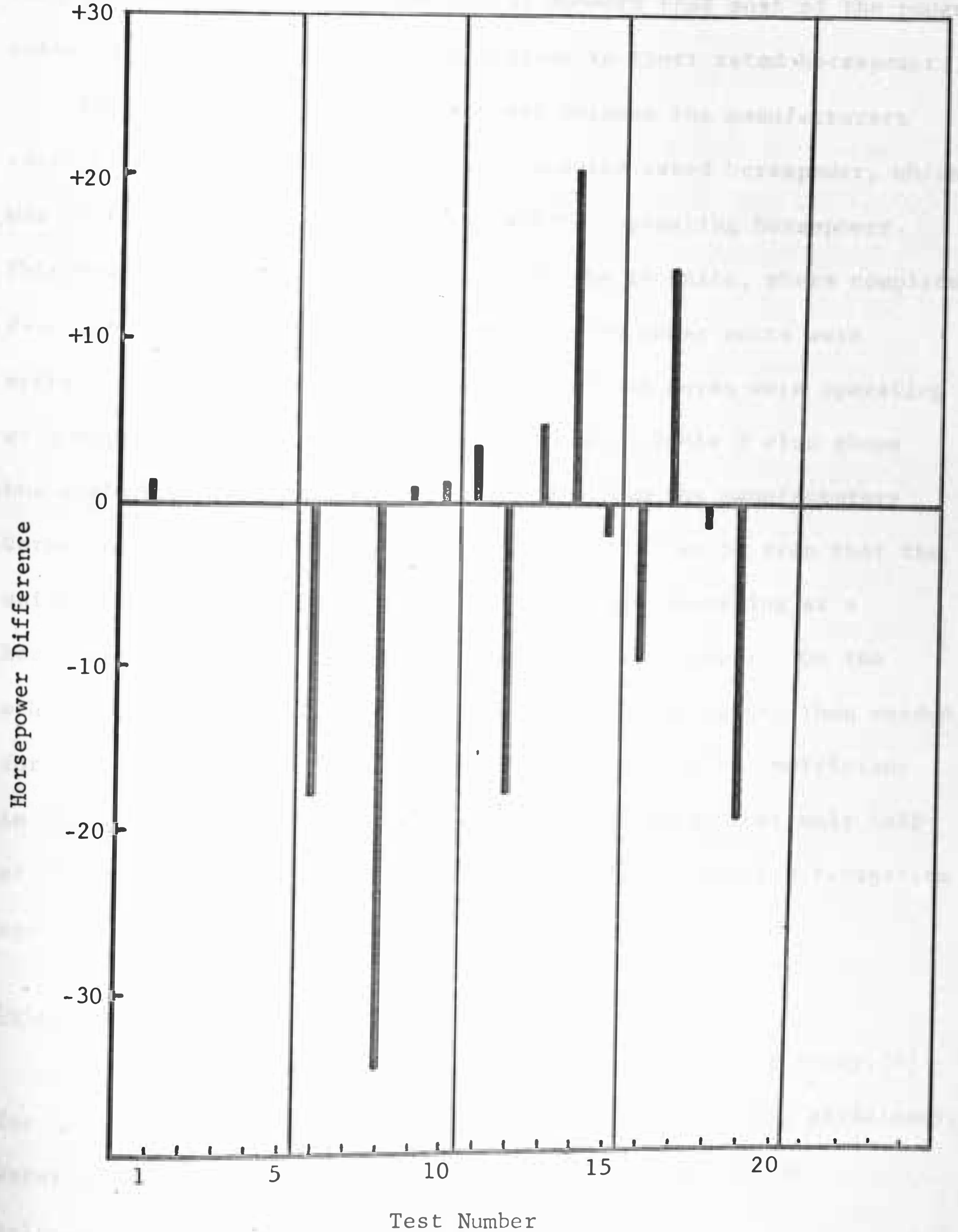


Fig. 5. DIFFERENCE OF OPERATING HORSEPOWER FROM MANUFACTURERS RATED HORSEPOWER.

test numbers 8, 14, 17, 11, and 13, it appears that most of the power units are being operated reasonably close to their rated horsepower.

The next horsepower comparison was between the manufacturers rated horsepower, the manufacturers corrected rated horsepower, which was corrected for all power losses, and the operating horsepower. This comparison is shown in Table 3. Of the 14 units, where complete data for this comparison was available, seven power units were operating at a higher horsepower than rated and seven were operating at a horsepower that was less than the rated. Table 3 also shows the difference of the operating horsepower from the manufacturers corrected rated horsepower. From this chart it can be seen that the units in tests 1, 9, 10, 11, 13, 15, and 18 are operating at a horsepower that is very close to their rated horsepower. On the other hand the units in tests 6, 8, 12, and 19 are larger than needed for their respective setups and as a result tend to be inefficient in their operation. This chart gives the indication that only half of the power units are matched closely to their respective irrigation systems.

Determination of Pump Efficiency

The water horsepower, as determined in a cooperative study,(4) for each test location was then used to determine the pump efficiency. Water horsepower is the horsepower output of a pump. It is calculated using the following formula:

$$\text{Water horsepower} = \frac{\text{gpm} \times \text{TDH}}{3960}$$

gpm = gallons per minute discharge from the pump

TDH = total dynamic head in feet of water.

The total dynamic head is the sum of the total static head, the friction loss in pipes and fittings, the discharge pressure and the velocity head. This formula was used in the cooperative study to determine the water horsepower.(4)

The horsepower comparison that was made was the operating horsepower available at the pump with the water horsepower. See Table 4. This comparison gives the actual efficiency of the pump. In horsepower comparisons the Nebraska Standard, 70% pump efficiency, is often assumed. In comparing the actual efficiency of these respective units, only the units in tests 1, 6, and 12 are above this 70% standard. See Fig. 6. The range of the efficiencies is from a high of 88% to a low of 20.5%. The mean pump efficiency in the study is 52.3% which is considerably lower than the assumed standard. Two conclusions could be drawn from these results. The first might be that the assumed standard is too high. It is however lower than the assumed standards that has been used in other work, where 75% was considered appropriate.(18, 26) The conclusion that would seem the most logical however, is that the pump is out of adjustment or did not meet the specifications required for the respective system. Specifications used in selecting a pump should include operating head, discharge requirements and minimum acceptable pump efficiency.(26) If the pump had been matched to the system the

Test No.	Operating Horsepower	Power Losses to Pump	HP Available at Pump	Water HP	Pump Efficiency
1	51.6	5[1]	49.0	41.5	84.8
2	--	--	--	6.8	--
3	--	--	--	5.4	--
4	--	--	--	42.5	--
5	28.0	5[1]	26.6	13.7	51.5
6	33.0	5[1]	31.3	27.8	88.0
7	--	--	--	--	--
8	19.44	5[1]	18.5	10.4	56.2
9	35.2	5[1]	33.6	8.6	25.6
10	21.5	10[2]	19.35	12.6	65.0
11	38.0	10[2]	34.2	7.0	20.5
12	15.3	10[2]	13.8	11.6	84.0
13	32.0	10[2]	28.8	8.2	28.5
14	47.0	--	47.0	13.3	28.4
15	24.0	--	24.0	15.8	65.8
16	56.2	--	56.2	31.9	56.7
17	45.0	--	45.0	21.5	47.7
18	45.0	5[1]	42.7	10.8	25.6
19	23.0	15[3]	19.6	11.1	56.6
20	--	--	--	62.5	--
21	--	--	--	67.0	--
22	--	--	--	--	--

NOTE:

1 Gear drive loss.

2 Belt drive loss.

3 Both gear and belt drive loss.

Average Efficiency = 52.3%

Tabel 4. PUMP EFFICIENCY AS DETERMINED BY ENGINE HORSEPOWER AND WATER HORSEPOWER.

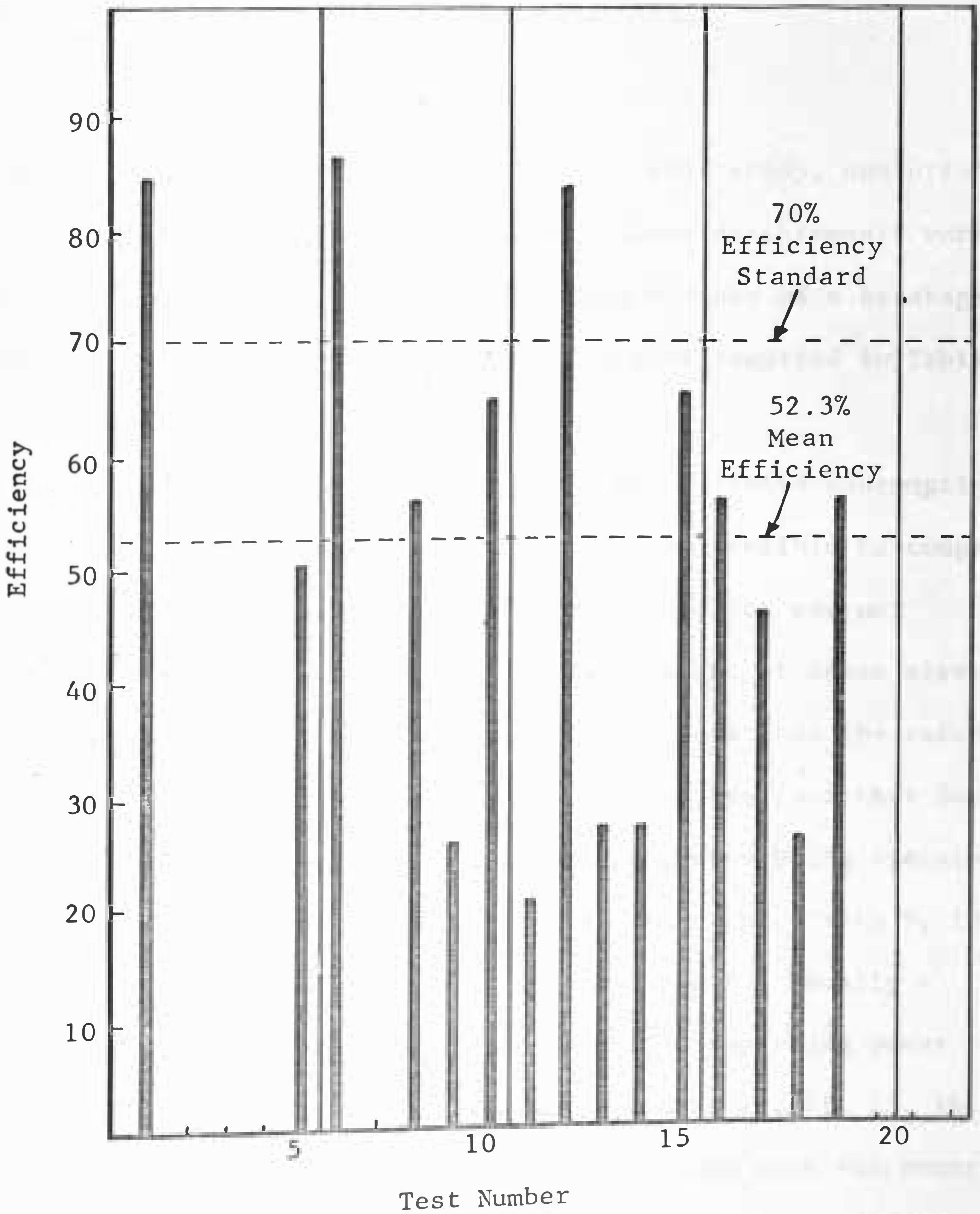


Fig. 6. OPERATING PUMP EFFICIENCY

next possibility would be that it is out of adjustment or that there was excessive wear on the impellers. The pumps in tests 9, 11, 13, 14, 17, and 18 definitely need inspection for the cause of poor efficiency. This study indicates that the efficiency of the irrigation pump is an area that needs attention.

Fuel Consumption and Economy

While horsepower was being measured for this study, concurrent fuel consumption measurements were taken. These measurements were not taken for the units burning propane (LP) because of a breakage in the test equipment. This consumption data is compiled in Table 5 and shown graphically in Fig. 7.

The operating consumption is compared to the rated consumption for the gasoline and diesel engines. It was not possible to compare the natural gas units because their rated consumption was not available. It is interesting to note that in eight of these eleven comparisons, the operating fuel consumption is less than the rated consumption. This can be explained partially by the fact that four of these eight units, tests 12, 15, 18, and 19, were being operated at less than 100% of rated power. Three of the eight, tests 9, 10, and 11, were being operated at close to rated power. Usually a direct relationship between fuel consumption and operating power exists, and this was indicated in six units, tests 10, 11, 13, 14, 15, and 18. In test 12, it seems reasonable to presume that the power unit needs a carburetion or ignition adjustment. This particular unit did "miss" when it was put under full load.

Test No.	Fuel Type	Rated Consumption Gal/Hr	Operate Consumption Gal/Hr[1]	Operating Consumption as % of Rated	Operating HP as % of Rated Horsepower
1	LP	7.47	5.94[2]	--	--
2	LP	NA	--	--	--
3	LP	NA	--	--	--
4	LP	NA	--	--	--
5	Gas	NA	226.0	--	--
6	Gas	NA	273.0	--	--
7	Gas	NA	647.0	--	--
8	Gas	NA	162.0	--	--
9	Gasoline	4.8	2.31	48%	103.0%
10	Gasoline	2.5	2.01	80%	106.0%
11	Gasoline	3.3	2.69	81%	111.0%
12	Gasoline	3.3	2.64	80%	46.2%
13	Gasoline	3.0	3.5	117%	118.0%
14	Diesel	2.6	2.7	104%	178.0%
15	Diesel	2.8	1.8	64%	92.0%
16	Diesel	4.6	4.7	102%	85.0%
17	Diesel	3.0	2.35	78%	148.0%
18	Diesel	3.8	2.01	53%	97.0%
19	Diesel	3.6	2.43	67%	54.0%
20	Diesel	NA	5.45	--	--
21	Diesel	NA	5.5	--	--
22	Propane	7.8	--	--	--

NOTE:

1 Fuel consumption for Natural Gas units in tests 5, 6, 7, and 8 is in cubic feet per hour.

2 Owners estimate.

Table 5. COMPARISON OF OPERATING AND RATED FUEL CONSUMPTION.

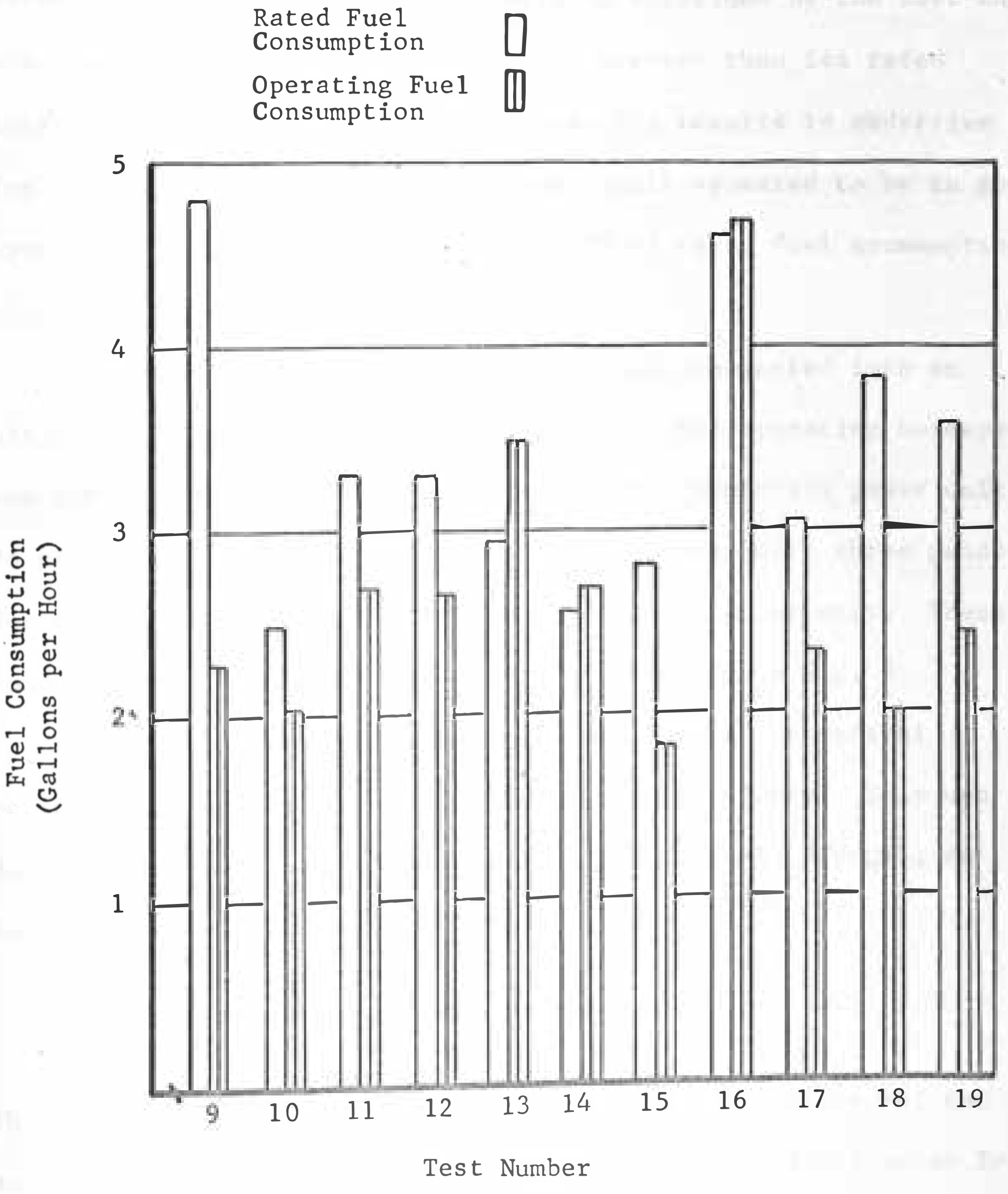


Fig. 7. COMPARISON OF THE OPERATING FUEL CONSUMPTION WITH THE RATED FUEL CONSUMPTION.

In tests 13, 14, and 16 the operating consumption exceeded the rated. In tests 13 and 14 this could be explained by the fact that the power unit was operating at a load greater than its rated horsepower. This type of operation usually results in excessive fuel consumption. In test 16 the power unit appeared to be in good operating condition, therefore, the 102% of rated fuel consumption should not be a matter of concern.

The fuel consumption of these units was converted into an efficiency figure. This was done by taking the operating horsepower and dividing by the fuel consumption of the respective power unit to give HP-hrs/gal. These results were compared with three guides for estimating the expected performance from a power unit. These comparisons are shown in Table 6 and graphically in Fig. 8.

The first guide for comparison was with the theoretical performance standard, which is the thermal efficiency. This was determined by converting the heating value of fuel, BTU/gal, to horsepower hrs/gal using the formula below:

$$1 \text{ HP} = 2545 \text{ BTU/hr}$$

This gives a standard that cannot be matched in practice but can serve as a guide. Normally, according to the Nebraska Tractor Test results, the thermal efficiency of a new engine will be about 20%.(26) In making a comparison with the measured operating efficiency it was found that tests 5, 6, 8, 14, 17, and 18 have an

Test No.	Measured Operating Performance HP-Hrs/Gal[3]	Theoretical[1] Performance Standard HP-Hrs/Gal[3]	Expected[2] Performance Standard HP-Hrs/Gal[3]	Mfg. Expected Performance For Corrected Rated HP HP-Hrs/Gal
1	8.7	36.0	11.2	6.72
2	--	36.0	11.2	--
3	--	36.0	9.9	--
4	--	36.0	11.2	--
5	124.0	444.0	102.2	--
6	121.0	444.0	102.2	--
7	--	444.0	91.0	--
8	120.0	444.0	102.2	--
9	15.2	50.2	14.1	7.2
10	10.7	50.2	12.6	8.2
11	14.1	50.2	12.6	10.3
12	7.3	50.2	12.6	10.0
13	9.15	50.2	12.6	9.2
14	17.4	55.4	16.4	10.3
15	13.2	55.4	16.4	9.2
16	12.0	55.4	16.4	14.2
17	19.2	55.4	16.4	10.0
18	22.4	55.4	18.4	12.2
19	9.5	55.4	14.75	11.8
20	--	55.4	18.4	--
21	--	55.4	18.4	--
22	--	55.4	11.2	--

NOTES:

[1] Thermal efficiency as determined from the heating values of fuel.(26)

[2] From Nebraska Tractor Test D information and Corrected for respective drive losses.(26)

[3] Fuel performance for the Natural Gas units in tests 5, 6, 7, and 8 is measured in HP-Hrs/1000 ft^3.

Table 6. COMPARISON OF OPERATING FUEL PERFORMANCE WITH PERFORMANCE STANDARDS.

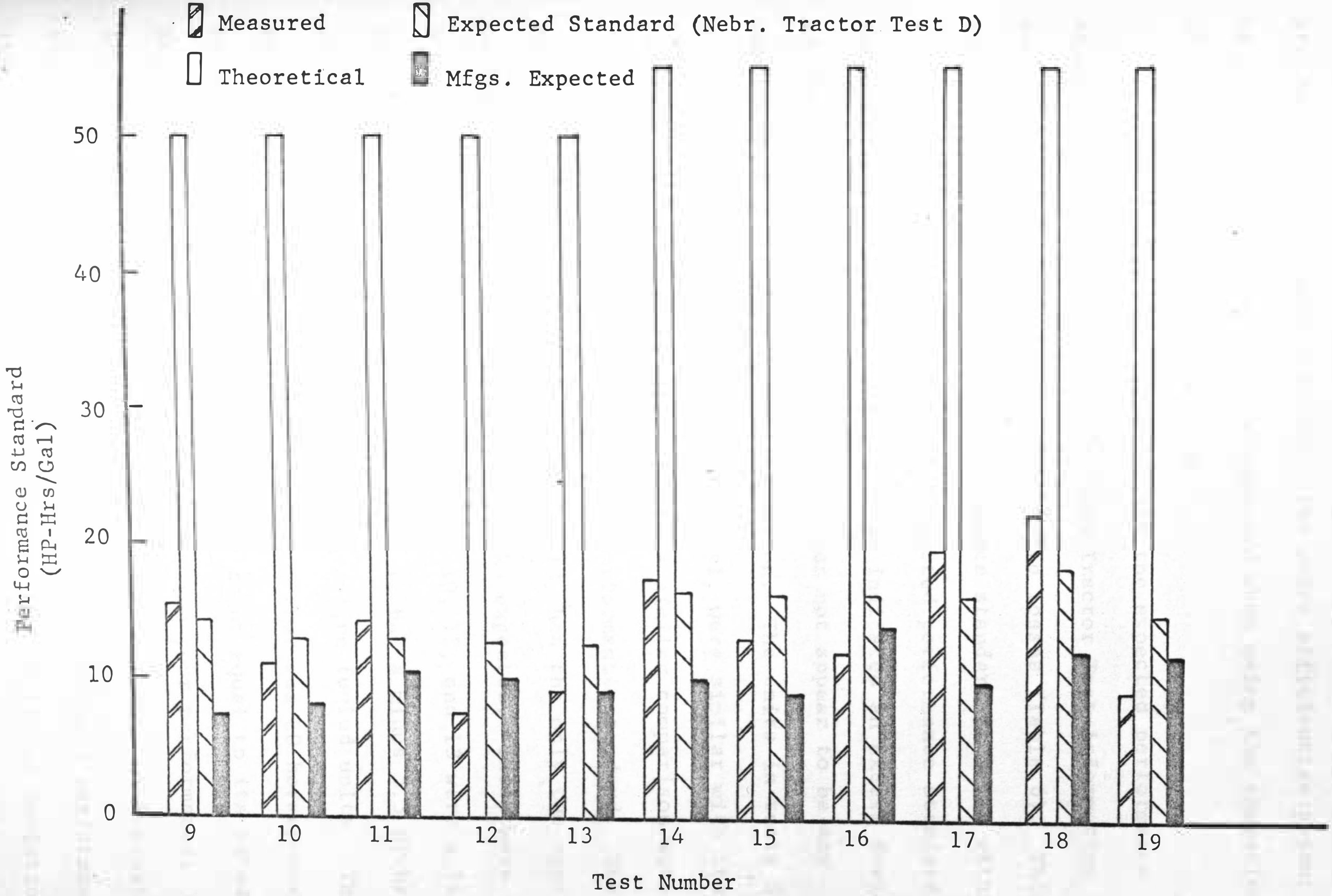


Fig. 8. GRAPHICAL COMPARISON OF OPERATING FUEL PERFORMANCE WITH PERFORMANCE STANDARDS.

efficiency that exceeds this 20%. The other efficiencies appear to be within a range that might be expected when using the comparison of 20% of theoretical performance.

A second comparison was made with the expected performance standard as obtained from the Nebraska Tractor Test information and making allowance for respective drive losses (Table 6). This comparison shows the measured performance standard as being within a reasonable range of the Nebraska expected performance standard. In tests 5, 6, 8, 14, 17, and 18, which indicated an excess deviation in the theoretical comparison, there does not appear to be any unreasonable deviation in this comparison. The units in tests 5, 6, and 8, which used natural gas for fuel, were similar with their measured performance and therefore had a similar comparison with the theoretical and the Nebraska expected performance standard. The gasoline fueled units, tests 9 through 13, had the only two operating performances that were above the Nebraska expected. These were tests 9 and 11. The other three units, tests 10, 12, and 13 were a little lower than the Nebraska standard. Test 12 had a minus 5.3 HP-hr/gal deviation which was the lowest of the gasoline fueled units. This particular unit had a measured horsepower that was 20 horsepower below its rated, and a fuel consumption about equal to its rated. These combined results would account for the poor performance. Of the diesel units compared, tests 14 through 19, with the Nebraska standard, those in tests 14, 17, and 18 had a measured performance that was higher. The unit in test 18 had a 4 HP-hr/gal deviation, which might be accounted for by its low, 50% of rated, measured fuel consumption. Test 19 had the largest minus deviation, minus 5.25 HP-hrs/gal, which corresponds to a measured operating horsepower that was 19.6 horsepower below its rated horsepower.

A third comparison was made between the measured performance and the manufacturers' expected performance for the units corrected rated horsepower (Table 6). The manufacturers' performance rating was not available for the natural gas fueled units so no comparison could be made for these. For the gas units, four of the five tested gave a better performance than the manufacturers' predicted. Tests 9 and 11 were consistent with the other comparisons in that they had the largest positive deviation from the manufacturers' predicted. This would give each of them a rating of being a very efficient power unit. The unit in test 12 had the largest minus deviation which reflects again on its low operating horsepower. The diesel units, with exception of tests 16 and 19, had a better measured performance than the manufacturers' expected performance. The units in tests 16 and 19 had the only minus deviation which again reflects on their low operating horsepower as compared to their rated.

The pumping plant efficiency was compared, on the basis of water horsepower per gallon of fuel with a Nebraska performance standard as shown in Table 7 and graphically in Fig. 9. The Nebraska standard is based on 75% pump efficiency and Nebraska Tractor Test reports.(26) This standard was set such that all pumping plants should equal, or

Test No.	Type of Fuel	Nebraska[1] Performance Standard WHP-Hr/Gal	Operating Performance Efficiency WHP-Hr/Gal	Deviation from Standard	% Deviation from Standard
1	Propane	6.69	6.99[2]	+ .30	+ 4.48%
2	Propane	6.69	--	--	--
3	Propane	6.69	--	--	--
4	Propane	6.69	--	--	--
5	Nat.Gas	61.4/1000 ft^3	60.62	- .78	- 1.27%
6	Nat.Gas	61.4/1000 ft^3	50.92	-10.48	-17.07%
7	Nat.Gas	61.4/1000 ft^3	--	--	--
8	Nat.Gas	61.4/1000 ft^3	64.2	+ 2.8	+ 4.56%
9	Gasoline	8.48	3.72	- 4.76	-56.13%
10	Gasoline	8.48	6.27	- 2.21	-26.06%
11	Gasoline	8.48	2.60	- 5.88	-69.34%
12	Gasoline	8.48	4.39	- 4.09	-48.23%
13	Gasoline	8.48	2.34	- 6.14	-72.41%
14	Diesel	11.06	4.93	- 6.13	-55.42%
15	Diesel	11.06	8.68	- 2.38	-21.52%
16	Diesel	11.06	6.79	- 4.27	-38.61%
17	Diesel	11.06	9.15	- 1.91	-17.27%
18	Diesel	11.06	5.37	- 5.69	-51.45%
19	Diesel	11.06	4.57	- 6.49	-58.68%
20	Diesel	11.06	11.47	+ .41	+ 3.71%
21	Diesel	11.06	12.18	+ 1.12	+10.13%
22	Propane	6.69	--	--	--

NOTE:

[1] Based on 75% pump efficiency.

[2] Owners estimate of fuel consumption.

Table 7. COMPARISON OF OPERATING PERFORMANCE WITH NEBRASKA PERFORMANCE STANDARD.

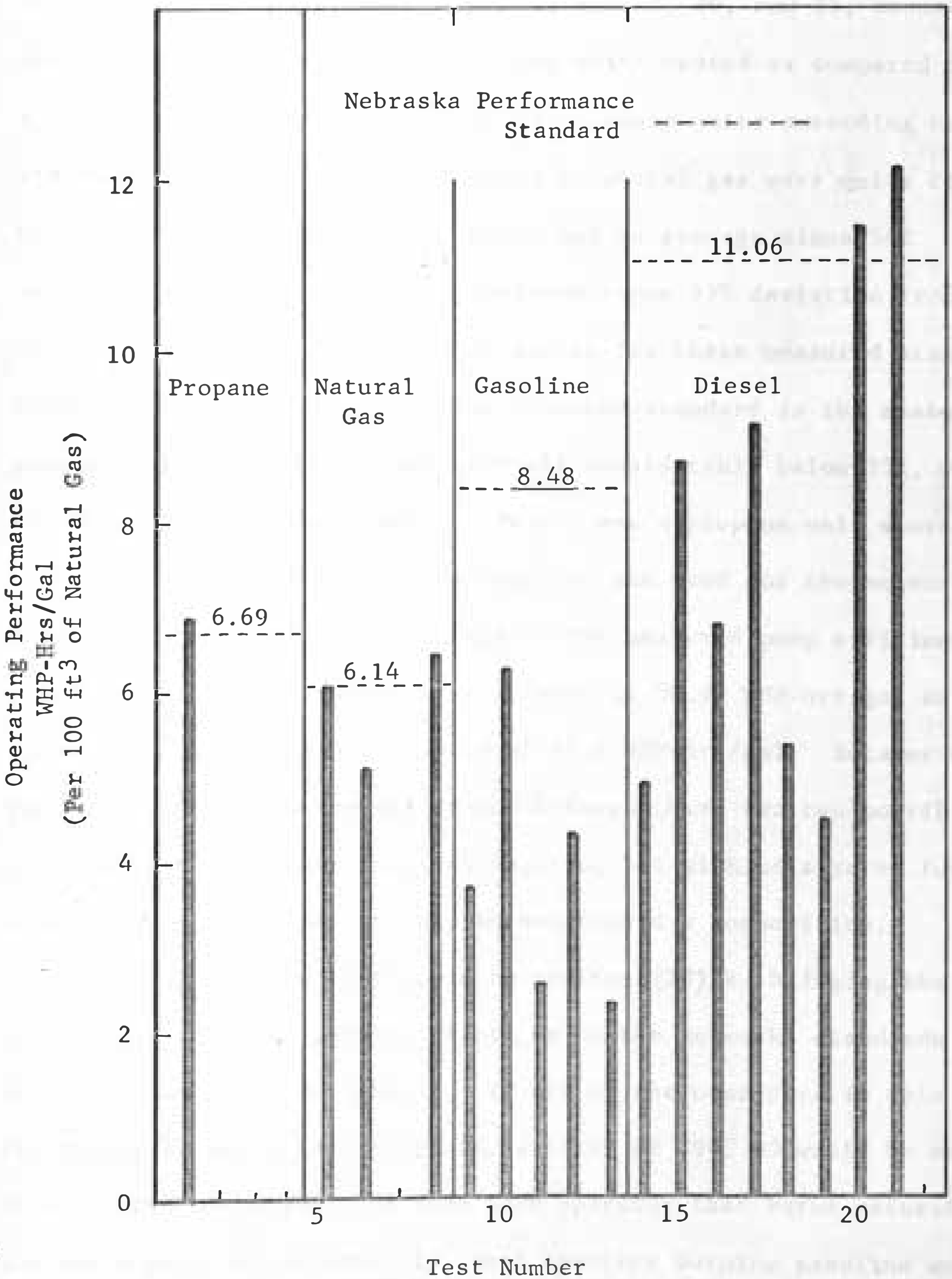


Fig. 9. OPERATING PERFORMANCE COMPARED WITH NEBRASKA STANDARDS.

be greater than, its level for the respective fuel. Of the units tested for this study, only four, tests 1, 8, 20, and 21, exceeded these standards. This was 20% of the units tested as compared to a Nebraska study that showed only 9% of their units exceeding the standard.(8) All of the units burning natural gas were quite close to the standard. The gasoline units had an average minus 54% deviation and the diesel units averaged minus 29% deviation from the standard. Probably the major reason for these measured standards being consistently lower than the Nebraska standard is the measured pump efficiency in this study were all considerably below 75%, with the exception of tests 1 and 6. Test 1 was a propane unit where the owner's estimate of fuel consumption was used and the measured pump efficiency was 84.5%. In test 6 the measured pump efficiency was 84.2% but the performance efficiency is 50.92 WHP-hrs/gal as compared to the Nebraska standard of 61.4 WHP-hrs/gal. Because of good pump efficiency the difference between these two can possibly be attributed to excess fuel consumption, but without a rated fuel consumption guide this can only be considered a supposition.

The fuel savings that could be realized(20) by bringing the performance of these pumping plants up to the Nebraska standards was determined as shown in Table 8. If all of the operators in this study were to equal this standard, a total of $965.05 would be saved in one year. Breaking this down each operator that burns natural gas would save $11.02 annually, each operator burning gasoline would save $102.80 annually, and each operator burning diesel fuel would

Test No.	Type of Fuel	Nebraska(26) Performance Standard WHP-Hr/Unit of Fuel[1]	Measured Performance WHP-Hr/Unit of Fuel[1]	Performance Rating % of Standard	Potential Amount of Fuel[2] That Could Be Saved in 100 Hrs of Operation(20)	Fuel[3] Cost/Unit (Cents)	Potential Annual Savings[4] (500 Hrs. Ann. Use) (Dollars)
1	Propane	6.69	6.99	104	none	none	none
2	Propane	6.69	--	--	--	--	--
3	Propane	6.69	--	--	--	--	--
4	Propane	6.69	--	--	--	--	--
5	Nat.Gas	61.4	60.62	99	100	4.5	2.25
6	Nat.Gas	61.4	50.92	83	8800	4.5	19.80
7	Nat.Gas	61.4	--	--	--	--	--
8	Nat.Gas	61.4	64.2	105	none	--	--
9	Gasoline	8.48	3.72	44	134	19.6	131.50
10	Gasoline	8.48	6.27	74	51	19.6	50.00
11	Gasoline	8.48	2.60	31	130	19.6	127.50
12	Gasoline	8.48	4.39	52	106	19.6	104.00
13	Gasoline	8.48	2.34	28	103	19.6	101.00
14	Diesel	11.06	4.93	45	118	14.5	85.50
15	Diesel	11.06	8.68	78	39	14.5	28.25
16	Diesel	11.06	6.79	61	188	14.5	136.00
17	Diesel	11.06	9.15	83	42	14.5	30.40
18	Diesel	11.06	5.37	49	72	14.5	52.10
19	Diesel	11.06	4.57	41	135	14.5	97.75
20	Diesel	11.06	11.47	104	none	--	none
21	Diesel	11.06	12.18	110	none	--	none
22	Propane	6.69	--	--	--	--	--

NOTES:
1 Gallons for gasoline, propane, and diesel; 1000 ft^3 for natural gas.
2 Gallons for gasoline, propane, and diesel; ft^3 for natural gas.
3 Price quoted by local dealers, per gallon for gasoline, propane, and diesel; per 100 ft^3 for natural gas.
4 Average use as surveyed in 1963 by Fred Schmer, Extension Irrigation Specialist.

Table 8. POTENTIAL FUEL SAVINGS DETERMINED BY COMPARING MEASURED WHP-HR/UNIT OF FUEL WITH STANDARD.

save \$71.67. This indicates that those operators burning gasoline or diesel fuel could gain financially by taking better care of their respective units. This additional care would be reflected in fuel savings.

CONCLUSIONS

Based on the experiences and results of this study the following conclusions can be drawn. Because of the limited number of power units tested these conclusions cannot be construed as representative of all irrigation power units. The conclusions must only be applied to the units of this one study.

1. The test equipment was adequate but it would simplify the study if it were more compact and easier to attach to the pumping equipment. Considerably more time was spent in attaching and detaching the test equipment from the power unit than was spent in testing.
2. Most of the power units tested were operating, in the author's opinion, in a reasonable range of their rated horsepower.
3. The pump efficiency was considerably below the accepted standards. This indicates that these pumps needed adjustment or repair.
4. The fuel efficiency of the power units was relatively close to rated in most cases. This apparently is not a problem area.
5. The maintenance of the units was poor. Only three units could be considered as free of any deficiencies. Better

performance could be obtained if the units were maintained properly. A low operating temperature was apparent in the majority of the units tested.

6. There are inefficiencies existing in the pumping plants. Most of these can be attributed to poor pump adjustment and poor engine maintenance.

7. The source of a deficiency in a pumping plant could be located by submitting that plant to a series of tests similar to those conducted in this study.

SUMMARY

This study was an evaluation of 22 irrigation power units. These units were of a variety of types and were fueled with four different fuels. Results of the study were gathered for horsepower, fuel consumption and maintenance deficiencies.

In the horsepower portion of the study, methods of measuring this horsepower had to be devised. A torquemeter and a strain gauge bridge amplifier were used to measure horsepower in the gear driven units. A Power-Take-Off Dynamometer was used for the belt driven units.

The fuel consumption was measured directly with the use of an auxiliary supply of fuel in calibrated cylinders. The gas meter was used for obtaining natural gas consumption.

There were not sufficient power units tested for the results of this study to be considered as representative of all irrigation power units. However, this study gives an indication of areas of deficiency in the pumping plant. These are areas where more investigation should be carried on to determine if the study indications are reliable.

Approximately one-half of the power units tested were being operated at a horsepower output that was fairly close to their respective rated horsepower. Only two of the units checked were significantly too small for their respective horsepower requirements and four units were considerably larger than what was needed.

The horsepower available at the pump was compared with the water horsepower produced by the pump to determine the pump's efficiency. The mean pump efficiency in this study was 52.3%. This is considerably lower than the 70% or 75% pump efficiency that is generally considered as a standard.

The fuel consumption of eight of the 11 units tested was less than the rated consumption. Seven of the eight units were being operated at less than rated load, however, so this could account for the lower consumption rate. Three comparisons of the fuel efficiency were made. These were with the theoretical standard, the Nebraska standard and the manufacturers rated consumption. As might be expected the fuel efficiencies were directly rated to the operating load and, therefore, quite predictable.

The plant efficiency on the basis of water horsepower per unit of fuel was also determined. Only four of the units tested exceeded the Nebraska standard; however, these results were quite similar to the ones obtained in a similar, but much larger, study that was made in Nebraska.

Only three of the 22 units checked were found to be void of any maintenance deficiencies. Cooling system deficiencies were the most numerous. They were found on 14 units. Nine units had ignition deficiencies and four had something wrong with the fuel or air systems.

RECOMMENDATIONS FOR FUTURE STUDIES OF THIS TYPE

A future study of this type could be simplified by some of the experiences encountered in this study. It is quite important in one of these studies that interference with the farmers time be kept to a minimum. Therefore, the testing time must be kept as short as possible.

In analyzing the testing equipment used in this study it is felt that it was adequate but quite bulky. Refinement in the horsepower testing equipment would be quite desirable. Its size and weight, particularly for PTO and belt horsepower testing, was excessive. Except for size, the dynamometer was easy to attach to the engines. The torquemeter was of a convenient size but was difficult to attach. It was quite common to find bolts and nuts rusted together and the drive shaft in an awkward location to remove.

An ideal horsepower measuring device would be an instrument that would be light and that could be clamped onto a drive shaft with a minimum of effort. In almost all cases the attachment and detaching of the horsepower measuring instruments, in this study, took more time than the actual testing.

The fuel and temperature measuring instruments were adequate and convenient to attach.

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APPENDICES

Appendix A. Linear Regression Calculation.

LINEAR REGRESSION CALCULATIONS

Average All Tests - M & W Dynamometer

$$\Sigma y^2 = (3091.4 + 3091.4 + 3080.2 + 3003 + 2937.6) - \frac{(275.7)^2}{5} = \underline{\underline{1.5}}$$

$$\Sigma x^2 = 6250$$

$$\Sigma xy = (19{,}460 + 20{,}850 + 22{,}200 + 23{,}290 + 24{,}390) - 110{,}280 = \underline{\underline{-90}}$$

$$b = \frac{-90}{6250} = \underline{\underline{-.01}} \qquad a = 55.1 - (-.01)\,400 = \underline{\underline{59.1}}$$

$$R^2 = \frac{8100}{9375} = \underline{\underline{.86}}$$

Average All Tests - M & W Dynamometer Corrected

$$\Sigma y^2 = (1354.24 + 1505.44 + 1664.64 + 1849 + 2025 + 2209)$$

$$- \frac{(251.4)^2}{6} = \underline{\underline{73.72}}$$

$$\Sigma x^2 = (1{,}031{,}875) - 1{,}020{,}937 = \underline{\underline{10{,}938}}$$

$$\Sigma xy = (12{,}880 + 14{,}550 + 16{,}320 + 18{,}275 + 20{,}250 + 22{,}325)$$

$$- 103{,}702.5 = \underline{\underline{897.5}}$$

$$b = \underline{\underline{.08}} \qquad a = 42 - (.08)\,412.5 = \underline{\underline{9}}$$

$$R^2 = \frac{805{,}506}{806{,}349.4} = \underline{\underline{.99895}}$$

Average All Tests - Clayton Dynamometer

$$\Sigma y^2 = (1102.24 + 1239.04 + 1383.84 + 1513.21 + 1664.64) - 6867.2$$

$$= \underline{\underline{35.77}}$$

$$\Sigma x^2 = 6250$$

$$\Sigma xy = (11{,}620 + 13{,}200 + 14{,}880 + 16{,}532.5 + 18{,}360) - 74120 = \underline{\underline{472.5}}$$

$$b = \underline{\underline{(.08)}} \qquad a = 37.1 - .32 = \underline{\underline{5.1}}$$

$$R^2 = \frac{223{,}256}{223{,}562.5} = \underline{\underline{.9986}}$$

Appendix B. Calculation to Convert Instrument Strain Reading and Shaft Revolutions Per Minute to Horsepower.

CALCULATION TO CONVERT INSTRUMENT STRAIN READING AND SHAFT REVOLUTIONS PER MINUTE DIRECTLY TO HORSEPOWER

Instrument reading multiplication factor = .4

Symbols used:

δ = unit stress

$\mathcal{E}$ = Modulus of elasticity

ϵ = strain (microin/in)

T = torque

J = moment of inerta

c = distance from axis to outside of cross-section

d = shaft diameter

HP = horsepower

N = RPM = revolutions per minute

I = instrument reading = /.4

Measurements to be obtained - strain = (.4)(I)
RPM of Shaft

Information desired - Horsepower

Formula Derivation

$$\delta = \mathcal{E}\epsilon \qquad \delta = \frac{TC}{J} \qquad \mathcal{E}\epsilon = \frac{TC}{J}$$

$$T = \left(\frac{J}{C}\right)\left(\mathcal{E}\epsilon\right)$$

$$HP = \frac{TN}{63000} = \frac{\left(\frac{J}{c}\right)\left(\mathcal{E}\right)\left(\epsilon\right)\left(N\right)}{63000}$$

$$J = \frac{\pi d4}{32} = .0575 \qquad c = \frac{d}{2} = .44$$

$\mathcal{E}$ (Machine steel) = 28,600,000 psi = 28.6×10^{-6}

ϵ = (.4)(I)(10^{-6}) in/in

$$HP = \frac{(.13)(28.6)(.4)(I)(N)}{63000} = \frac{.0236}{1000}\ IN$$

Appendix C. Individual Test Data Sheets.

POWER UNIT DATA SHEET

Operator Verlyn Hybertson Test Number 1

I. Power Unit Specifications

Make and Model Minneapolis Moline

Serial No. 0360120 Year of Manufacture 1956

Type of Drive Gear Fuel Used Propane

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	1120	1500
Horsepower	51.6	66
Fuel Consumption	5.94 gal/hr	7.47 gal/hr
Engine Temperature	142°	180°

III. Maintenance Comments:

This power unit is designed to operate at 175° - 180°, therefore, it is being operated at a temperature that is 35° too low. Otherwise the engine was in excellent condition.

IV. Testing Comments:

Operators records for the past year were used to obtain fuel consumption rate. Rated fuel efficiency at corrected rated HP = 6.72 HP-Hrs/Gal.

POWER UNIT DATA SHEET

Operator Robert Donnelly   Test Number 2

I. Power Unit Specifications

Make and Model Allis-Chalmers W-226

Serial No. PU226-301137   Year of Manufacture NA

Type of Drive Gear   Fuel Used LP

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	1380	1800
Horsepower	--	50.2
Fuel Consumption	2 gal/hr	--
Engine Temperature	180^{o}	180^{o}

III. Maintenance Comments:

The battery was run down, needed a booster battery to get power unit started. The spark jumped from two plugs to engine housing when the power unit was under full load. Power unit is being operated at 420 RPM less than rated full load, probably because of ignition problems.

IV. Testing Comments:

We were unable to test for horsepower as nuts were froze on drive shaft bolts. Fuel consumption is estimate that was given by operator.

POWER UNIT DATA SHEET

Operator Ed Curry　　　　Test Number 3

I. Power Unit Specifications

Make and Model Ford 8 MNN

Serial No. 81872　　　　Year of Manufacture NA

Type of Drive Belt　　　　Fuel Used LP

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	1830	--
Horsepower	--	--
Fuel Consumption	--	--
Engine Temperature	150^{o}	--

III. Maintenance Comments:

The power unit is being operated at an engine temperature about 25^{o} lower than what it is designed for. To get the governor to operate properly a screwdriver was being used, to wedge it open, in place of a throttle.

IV. Testing Comments:

Because of location of power unit, we were unable to get horsepower readings. Was unable to obtain engine specifications from manufacturer.

POWER UNIT DATA SHEET

Operator Andy Reiners Test Number 4

I. Power Unit Specifications

Make and Model Chrysler-Industrial 56-A

Serial No. 15778 Year of Manufacture NA

Type of Drive Gear Fuel Used Propane

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	1980	2400
Horsepower	--	12.0
Fuel Consumption	--	--
Engine Temperature	130°	180°

III. Maintenance Comments:

Air cleaner was exceptionally dirty. Power unit was operating at low engine temperature. Engine missed when under load, and the ignition wires were cracked quite severely.

IV. Testing Comments:

Unable to take horsepower and fuel consumption data as bolts on drive shaft were "froze" and equipment for propane test did not work. Unable to obtain engine specifications from manufacturer.

POWER UNIT DATA SHEET

Operator ___Ed Curry___ Test Number ___5___

I. Power Unit Specifications

Make and Model ___Ford Industrial B6PF-6003-C___

Serial No. ___2849-G21CH___ Year of Manufacture ___NA___

Type of Drive ___Gear___ Fuel Used ___Natural gas___

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	1520	--
Horsepower	28	--
Fuel Consumption	226 ft^3/hr	--
Engine Temperature	120^o	180^o

III. Maintenance Comments:

Battery was low on water and also low on charge. Engine had to be started with a booster battery. Engine operating temperature was 60^o below that recommended. Ignition wiring was cracked very severely.

IV. Testing Comments:

Engine specifications not available from manufacturer.

POWER UNIT DATA SHEET

Operator Daryl Chicoine   Test Number 6

I. Power Unit Specifications

Make and Model Continental 5382

Serial No. 403   Year of Manufacture NA

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	1240	1400
Horsepower	33	74.2
Fuel Consumption	273 ft^3/hr	--
Engine Temperature	140^o	180^o

III. Maintenance Comments:

Engine temperature was about 40^o under that recommended.

IV. Testing Comments:

POWER UNIT DATA SHEET

Operator Jerald Hansen | Test Number 7

I. Power Unit Specifications

Make and Model Chrysler Industrial 24-A

Serial No. 1881 | Year of Manufacture NA

Type of Drive Belt | Fuel Used Natural gas

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	2160	--
Horsepower	--	--
Fuel Consumption	647 ft^3/hr	--
Engine Temperature	165°	180°

III. Maintenance Comments:

Engine and accessories were in excellent condition. Engine temperature was slightly low.

IV. Testing Comments:

Power unit was too large for dynamometer to test. Unable to obtain engine specifications from manufacturer.

POWER UNIT DATA SHEET

Operator Luther Neilson   Test Number 8

I. Power Unit Specifications

Make and Model Continental FA244

Serial No. 2258 1521   Year of Manufacture NA

Type of Drive Gear   Fuel Used Natural Gas

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	1500	2400
Horsepower	19.44	79
Fuel Consumption	162 ft^3/hr	--
Engine Temperature	150^o	180^o

III. Maintenance Comments:

Engine's temperature low.

IV. Testing Comments:

Unable to get fuel consumption data from manufacturer to make comparison. Power unit did not appear to be under full load.

POWER UNIT DATA SHEET

Operator Don Schrodemeir Test Number 9

I. Power Unit Specifications

Make and Model International 421

Serial No. UH 399U Year of Manufacture 1941

Type of Drive Gear Fuel Used Gasoline

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	1200	--
Horsepower	35.2	45.2
Fuel Consumption	2.31 gal/hr	4.8 gal/hr
Engine Temperature	165^o	185^o

III. Maintenance Comments:

Engine temperature was low. Vacuum hole plugged with carbon indicating that inside of intake manifold had deposit on it. Fuel line from tank was partially plugged with a black, slimy, foreign substance.

IV. Testing Comments:

Manufacturers rated RPM was not available.

POWER UNIT DATA SHEET

Operator Ray Lyle   Test Number 10

I. Power Unit Specifications

Make and Model Case 49 SC

Serial No. --   Year of Manufacture 1949

Type of Drive Belt   Fuel Used Gasoline

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	480	540
Horsepower	21.5	28.1
Fuel Consumption	2.01 gal/hr	2.47 gal/hr
Engine Temperature	--	--

III. Maintenance Comments:

There was no cup on air cleaner, therefore, non-filtered air was being drawn directly into engine. Engine killed when vacuum plug was pulled out.

IV. Testing Comments:

Engine, under operating load, was only turning the PTO at 480 RPM when at full throttle.

POWER UNIT DATA SHEET

Operator Jim Chicoine   Test Number 11

I. Power Unit Specifications

Make and Model John Deere 630

Serial No. 6312519   Year of Manufacture 1959

Type of Drive Belt   Fuel Used Gasoline

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	466	540
Horsepower	38	42.8
Fuel Consumption	2.69 gal/hr	3.32 gal/hr
Engine Temperature	170°	185°

III. Maintenance Comments:

The engine and battery both were low on water. Engine backfired when turned off.

IV. Testing Comments:

Unit was not operating under full load or full throttle.

POWER UNIT DATA SHEET

Operator Rollin Chicoine Test Number 12

I. Power Unit Specifications

Make and Model John Deere 620

Serial No. 6201105 Year of Manufacture 1955

Type of Drive Belt Fuel Used Gasoline

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	570	540
Horsepower	19.2	41.4
Fuel Consumption	2.64 gal/hr	3.32 gal/hr
Engine Temperature	180°	185°

III. Maintenance Comments:

Tractor missed when under full load.

IV. Testing Comments:

Tractor was not operating under full throttle.

POWER UNIT DATA SHEET

Operator Mark Fargo Test Number 13

I. Power Unit Specifications

Make and Model John Deere A

Serial No. 500816 Year of Manufacture 1940

Type of Drive Belt Fuel Used Gasoline

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	500	540
Horsepower	36	33.8
Fuel Consumption	3.5 gal/hr	2.96 gal/hr
Engine Temperature	140°	185°

III. Maintenance Comments:

There was no cap on radiator. Operating temperature of engine was low. Used a belt connected to belt pulley of another tractor to turn engine over to start. Tractor misfired when turned off. Engine had been overhauled previous winter.

IV. Testing Comments:

None

POWER UNIT DATA SHEET

Operator John Curry   Test Number 14

I. Power Unit Specifications

Make and Model Massey Harris 44

Serial No. --   Year of Manufacture NA

Type of Drive Belt   Fuel Used Diesel

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	1270	1350
Horsepower	51	36.7
Fuel Consumption	2.7 gal/hr	2.57 gal/hr
Engine Temperature	160°	190°

III. Maintenance Comments:

Battery charge was very low. Booster battery would not give enough power to start engine, therefore, an arc welder was hooked to ignition system for sufficient booster current. Owner had premature overhaul because of excess use of oil additive.

IV. Testing Comments:

None

POWER UNIT DATA SHEET

Operator Glen Knutson   Test Number 15

I. Power Unit Specifications

Make and Model Minneapolis Moline 283-4A

Serial No. 07700011   Year of Manufacture 1954

Type of Drive Belt   Fuel Used Diesel

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	1100	1100
Horsepower	28	36
Fuel Consumption	--	--
Engine Temperature	150°	190°

III. Maintenance Comments:

Engine and all components appeared to be in good condition.

Engine operating temperature was lower than recommended.

IV. Testing Comments:

None

POWER UNIT DATA SHEET

Operator Glen Knutson Test Number 16

I. Power Unit Specifications

Make and Model Oliver Super 199-D

Serial No. A 11010 D Year of Manufacture NA

Type of Drive Belt Fuel Used Diesel

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	1500	1500
Horsepower	60.2	73
Fuel Consumption	4.7 gal/hr	4.63 gal/hr
Engine Temperature	190°	190°

III. Maintenance Comments:

Engine and all components appeared to be in good condition.

IV. Testing Comments:

None

POWER UNIT DATA SHEET

Operator Jerald Hansen　　　Test Number 17

I. Power Unit Specifications

Make and Model Minneapolis Moline 283-4A

Serial No. --　　　Year of Manufacture NA

Type of Drive Belt　　　Fuel Used Diesel

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	1300	1300
Horsepower	49	42.0
Fuel Consumption	2.35 gal/hr	3.03 gal/hr
Engine Temperature	160°	190°

III. Maintenance Comments:

All engine components and accessories in excellent condition.

IV. Testing Comments:

None

POWER UNIT DATA SHEET

Operator Frank Powell Test Number 18

I. Power Unit Specifications

Make and Model Minneapolis Moline M-5(336-4)

Serial No. 11403967 Year of Manufacture 1962

Type of Drive PTO Fuel Used Diesel

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	410	540
Horsepower	49	58.1
Fuel Consumption	2.01 gal/hr	3.84 gal/hr
Engine Temperature	190^{o}	190^{o}

III. Maintenance Comments:

Tractor in excellent operating condition.

IV. Testing Comments:

Operates pump with power unit at part throttle.

POWER UNIT DATA SHEET

Operator Vincent Trudeau Test Number 19

I. Power Unit Specifications

Make and Model IHC ·560D

Serial No. 27240S Year of Manufacture 1960

Type of Drive PTO to Belt Fuel Used Diesel

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	620	540
Horsepower	27	53.2
Fuel Consumption	2.43 gal/hr	3.6 gal/hr
Engine Temperature	190^o	190^o

III. Maintenance Comments:

Battery was two quarts low on water. Needed booster battery to start. Generator overcharged, but this may possibly have been because of low charge in battery.

IV. Testing Comments:

Drive unit was belt pulley mounted on the PTO drive shaft. Pump ran off belt.

POWER UNIT DATA SHEET

Operator Leonard Dailey Test Number 20

I. Power Unit Specifications

Make and Model Deutz F8L614

Serial No. 1846 889-96 Year of Manufacture NA

Type of Drive Gear Fuel Used Diesel

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	1634	--
Horsepower	--	130
Fuel Consumption	5.45 gal/hr	--
Engine Temperature	--	--

III. Maintenance Comments:

Engine and components appeared in excellent condition.

IV. Testing Comments:

Power unit is German made and air-cooled. Was unable to test because of high horsepower and unable to obtain manufacturers data concerning engine. Rated horsepower given is that quoted by owner.

POWER UNIT DATA SHEET

Operator Yankton Corporation Test Number 21

I. Power Unit Specifications

Make and Model Deutz F8L614

Serial No. ---

Year of Manufacture NA

Type of Drive Gear

Fuel Used Diesel

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	1950	--
Horsepower	--	130
Fuel Consumption	5.5 gal/hr	--
Engine Temperature	--	--

III. Maintenance Comments:

Power unit had oil leak but was unable to determine source.

IV. Testing Comments:

This was a German manufactured, air-cooled power unit. Was unable to test because of high horsepower output and unable to obtain manufacturers data concerning engine. Rated horsepower is that quoted by owner.

POWER UNIT DATA SHEET

Operator Claude Sherard Test Number 22

I. Power Unit Specifications

Make and Model Minneapolis Moline 425-6A

Serial No. -- Year of Manufacture NA

Type of Drive Gear Fuel Used Propane

II. Data Comparison

	Measured at Operating Load	Manufacturers Rated
Revolutions per Minute	1200	1500
Horsepower	--	71.0
Fuel Consumption	--	--
Engine Temperature	160^o	180^o

III. Maintenance Comments:

Engine and all components in excellent condition. Engine operating temperature low.

IV. Testing Comments:

Was unable to check horsepower and fuel consumption as proper adapters weren't available for attaching instruments.

Appendix D. Test Data Summary.

SUMMARY OF RESULTS OF IRRIGATION
PUMPING PLANT TESTS

		Power Unit									
Name	Test No.	Make Model	Drive	Fuel	RPM	Fuel Consumption Gal/Hr	Operate Horse-Power	Fuel Economy HP-Hrs/Gal	Water H.P.	Pump Efficient	Operate Temperature Degrees
Hybertson	1	M.M. 425A-6A	Gear	Propane	1120	5.94*	51.6	8.7	41.5	84.8%	142
Donnelly	2	A.C. W-226	Gear	Propane	1380	--	--	--	6.8	--	180
Ed and Jim Curry	3	Ford 8 MNN	Belt	Propane	1830	--	--	--	5.4	--	150
Reiners	4	Chrys. Ind.56-A	Gear	Propane	1980	--	--	--	42.5	--	130
Ed and Jim Curry	5	Ford Ind.	Gear	Nat. Gas	1520	226 ft^3/Hr	28.0	124 HP-Hrs/1000 ft^3	13.7	49.0%	120
Daryl Chicoine	6	Cont.	Gear	Nat. Gas	1240	273 ft^3/Hr	33.0	121 HP-Hrs/1000 ft^3	27.8	84.2%	140
Hansen	7	Chrys. Ind.24-A	Belt	Nat. Gas	2160	647 ft^3/Hr	--	--	--	--	165
Neilson	8	Cont. FA-244	Gear	Nat. Gas	1500	162 ft^3/Hr	19.44	120 HP-Hrs/1000 ft^3	10.4	53.5%	150
Schrodemeir	9	Int. U-21	Gear	Gasoline	1200	2.31	35.2	15.2	8.6	24.4%	165
Lyle	10	Case 49SC	Belt	Gasoline	480	2.01	21.5	10.7	12.6	58.6%	--
Jim Chicoine	11	J.D. 630	Belt	Gasoline	466	2.7	38.0	14.1	7.0	18.4%	120
Rollin Chicoine	12	J.D. 620	Belt	Gasoline	570	2.64	19.2	7.3	11.6	60.4%	175
Fargo	13	J.D. A	Belt	Gasoline	500	3.27	32.0	9.8	5.3	16.6%	140

(continued)

Name	Test No.	Power Unit				Fuel Consumption Gal/Hr	Operate Horse-Power	Fuel Economy HP-Hrs/Gal	Water H.P.	Pump Efficient	Operate Temperature Degrees
		Make Model	Drive	Fuel	RPM						
John Curry	14	M.H. 44	Belt	Diesel	662	2.75	47.0	17.4	10.8	22.9%	160
Knutson	15	M.M. D283-4A	Belt	Diesel	342	1.82	24.0	13.2	15.8	65.8%	150
Knutson	16	Oliver Super 199	Belt	Diesel	398	4.7	56.2	12.0	31.9	56.8%	190
Hansen	17	M.M. D283-4A	Belt	Diesel	538	2.35	45.0	19.1	21.5	47.8%	160
Powell	18	M.M. M-5	PTO	Diesel	410	2.01	45.0	22.4	7.8	17.3%	180
Trudeau	19	IHC 560-D	PTO	Diesel	620	2.43	23.0	9.5	11.1	48.3%	--
Dailey	20	Deutz F82614	Gear	Diesel	1634	5.45	--	--	62.5	--	--
Yankton Corporation	21	Deutz F82614	Gear	Diesel	1950	5.5	--	--	67.0	--	--
Sherard	22	M.M. 425-6A	Gear	Propane	1200	--	--	--	--	--	160

* Owners' figures, yearly average.

Appendix E. Horsepower Obtained With Torquemeter.

Test No.	Bridge Amplifier Reading (in-lb)	Measured Check HP	Bridge Amplifier Reading (Microin/in)	Power Shaft RPM	Operating HP
1	2730	49.0	1230	1120	51.6
5	1030	25.0	800	1520	28.0
6	1750	34.5	1118	1240	33.0
8	825	19.61	540	1500	19.44
9	1825	34.8	1245	1200	35.2

HORSEPOWER OBTAINED WITH TORQUEMETER.